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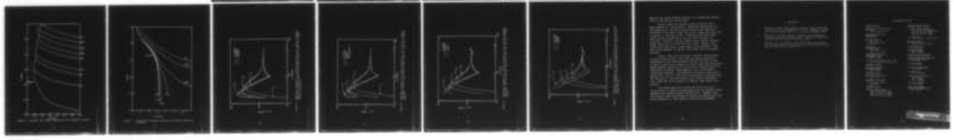

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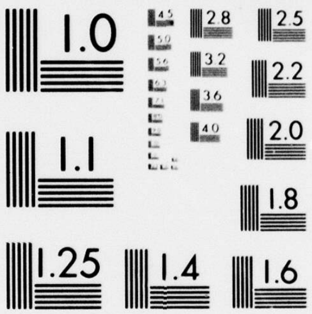

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Systems, Science and Software
P.O. Box 1620
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April 1978

Topical Report for Period October 1977—April 1978

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

An investigation was made of the coupling into the ground from a nuclear device detonated in an air-filled cavity using the spherically symmetric SKIPPER code. The calculations showed that small air-filled cavities couple stronger than tamped events in tuff. However, larger air-filled cavities became almost completely decoupled and do not have a significant compressive residual stress field.

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1. INTRODUCTION AND SUMMARY

An investigation was made of the coupling into the ground from a nuclear device detonated in an air-filled cavity. The hemispheric cavity containing a nominal one kiloton device was approximated in one-dimension as a spherical cavity with a two kiloton device surrounded by Rainier Mesa tunnel tuff. Several different initial configurations were used to model the device. These varied from a detailed calculation of the radiation propagation from the device using the Vera Code(1) to the simple model of the device energy initially deposited uniformly in the air-filled cavity. In all cases, the late time ground motion was calculated using the spherically symmetric SKIPPER(2) Code. The results a few mesh widths into the tuff were remarkably insensitive to the choice of initial configuration.

Calculations were made for a tamped 2 KT event and for initial cavity radii of 4, 8, and 16 meters. The primary purpose of these calculations was to examine the compressive residual stress fields about the cavity, and, in particular, to investigate whether the expected decoupling due to larger cavities would degrade these residual stress fields, thus increasing the likelihood of hydrofracture due to the hot cavity gases.

The important results of these calculations are the following:

(1) The teleseismic coupling as measured by the steady state value of the reduced displacement potential (RDP) was significantly greater for the 4 and 8 meter cavities than for the tamped case, as were the peak stresses in the tuff at ranges greater than approximately three cavity radii. Although the 16 meter cavity was largely decoupled, these surprising results may be of interest in yield determination.*

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*After this report was written, the authors learned that J. Trulio has recently investigated teleseismic coupling of explosions in granite cavities. Qualitatively similar results were obtained. J. G. Trulio, N. K. Pearl, G. N. Balanis, & R. G. Boyd, "Decoupling by small factors in underground nuclear tests," Applied Theory report ATR-77-45-1, Preliminary draft.

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(2) The residual stress fields in the tamped case and in the case of the 4 meter cavity appear to be sufficiently large to contain the hot cavity gases. However, for the 16 meter cavity, these stresses would certainly not be effective in preventing hydrofracture. The residual stress field for 8 meter cavity must resist a relatively high cavity pressure but may be contained. A detailed discussion of the calculations follows.

2. DISCUSSION

The tamped cavity calculations were initialized in two different ways -- first with the device energy of 2 KT deposited uniformly in the tuff within a radius of 2.5 meters, and second with it deposited within a radius of 0.94 meters (approximately 10 percent of the mass used for the first calculation). The CHEST 24 equation of state(3) was used to model the behavior of the tuff within the cavity and around it. The tuff for all calculations had a bulk density of 1.90 gms/cm^3 and 2.6 percent air-filled voids. A parabolic failure envelope with a maximum stress difference of 0.50 kbars above a pressure of 0.8 kbars and a stress difference at zero pressure of 0.06 kbars was used for the tuff.

The other calculations of the study assumed an air-filled cavity modeled by a tabular equation of state. Column 1 of Table 1 summarizes these calculations. Calculations 1 and 2 are the tamped cavity calculations described above. Calculations 3 and 4, for an initial cavity radius of 4 meters, have been initialized with the device energy deposited in the entire air mass and in 10 percent of the air mass, respectively. For calculations 5 and 6, the energy was deposited within a 8 meter radius in both cases.

The reduced displacement potential (RDP) is a measure of the teleseismic body wave magnitude radiated by the explosion. Column 2 of Table 1 gives the steady state value of the RDP for each of the calculations. These results surprisingly indicate that teleseismically, at least, the tamped device does not couple into the ground as well as the devices detonated in the 4 and 8 meter cavities. However, the 16 meter cavity clearly decouples the teleseismic ground motion.

Table 1. Calculational Results

Description	RDP(m^3)	% Energy in Cavity	Cavity Radius (m)	Cavity Pressure (bars)	Peak Residual Stress (bars)	
					σ_R	σ_θ
1. Tamped (uniform)	318	34	16.5	195	365	571
2. Tamped (10%)	272	37	15.9	180	357	545
3. R_o=4m (uniform)	430	27	18.3	222	390	584
4. R=4m (10%)	450	20	18.5	183	365	563
5. R_o=8m	427	54	18.5	355	452	634
6. R_o=16m	144	92	17.6	714	714	490

Figure 1 shows peak stress vs. range for the different initial cavity radii. In close to the cavity, peak stresses are greatest for the tamped case and decrease as the initial cavity is made larger. Further out, except for the case of the 16 meter cavity, the curves reverse their relative position so that at distances greater than approximately 200 meters, the coupling as measured by peak stress is qualitatively similar to that suggested by the RDP.

Column 3 of Table 1 shows the energy remaining in the cavity at late time (0.3 sec) as a percentage of the device energy. Over one-third of the initial energy remains in the cavity for the tamped calculations while only about 25 percent remains behind in the 4 meter cavity. This result is completely compatible with the comparisons presented before, i.e., the computational evidence is that the 4 meter, air-filled cavity does not decouple the device, but in fact enhances the coupling. The calculations do not clarify at which cavity radius the ground motion begins to be decoupled from the device. While peak stress and RDP indicate that the 8 meter cavity is still strongly coupled, over 50 percent of the device energy remained in the 8 meter cavity.

Some insight may be obtained by examining the calculated final cavity radii, shown in Column 4 of Table 1. The computed cavity radii for the 4 and 8 meter calculations are approximately the same, i.e., significantly less work has been done to expand the 8 meter cavity; thus the higher energy remaining in the cavity. For the identical final cavity size and assuming that exactly a factor of 2 more energy remains inside the 8 meter initial cavity when compared to the 4 meter cavity, the 8 meter cavity would have a pressure a factor of 2 higher than the 4 meter cavity. This agrees with the calculated cavity pressure shown in Column 5 of Table 1.

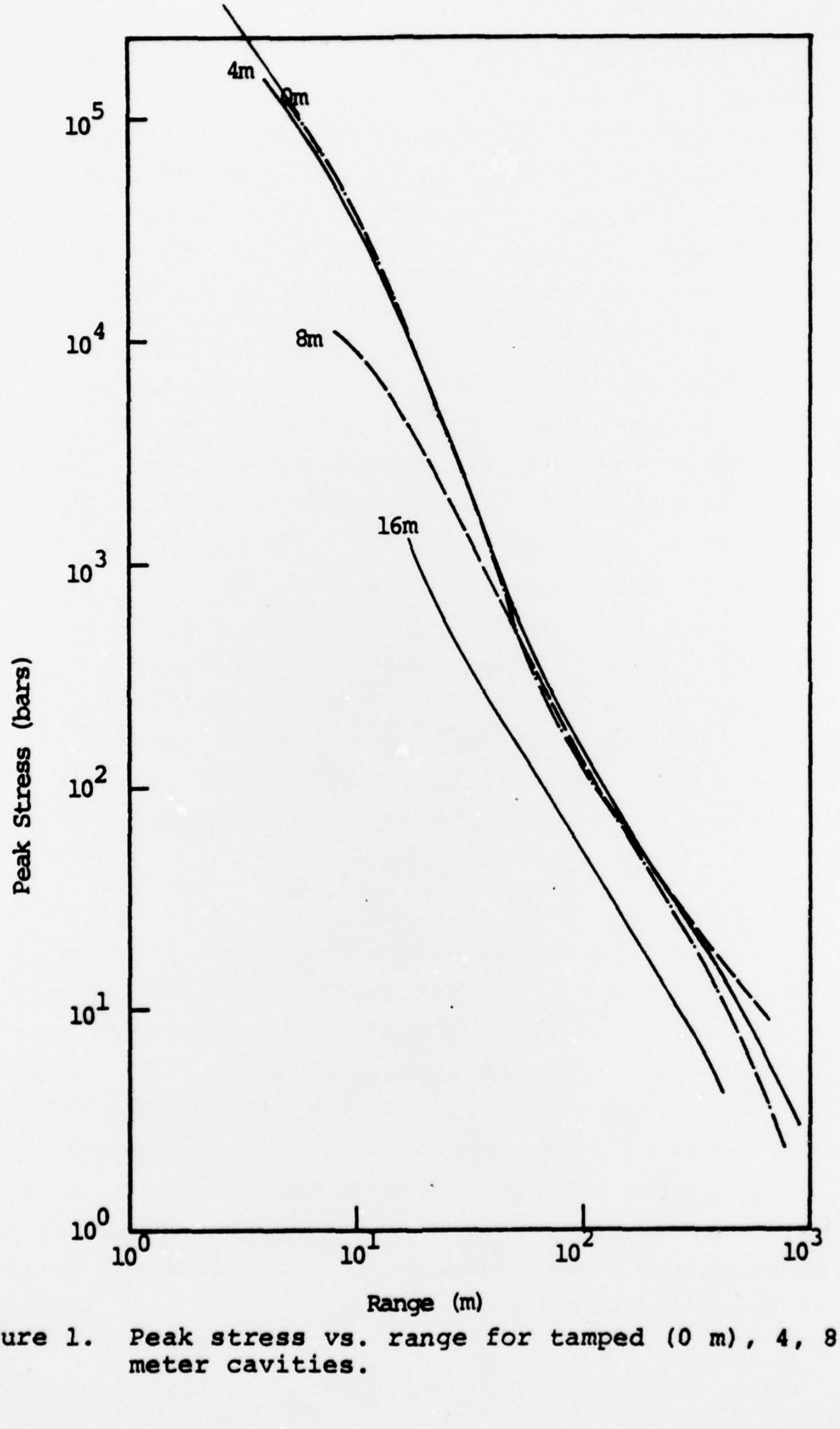

Figure 1. Peak stress vs. range for tamped (0 m), 4, 8 and 16 meter cavities.

To find an explanation for the strong coupling of the 4 and 8 meter cavities, we must look at the equation of state of air and of the tuff. Figure 2 gives the Hugoniot and some release adiabats for the air equation of state (V_o = 1000, not shown on the graph), while Figure 3 shows similar curves for the CHEST 24 tuff equation of state. Note that the tuff release isentropes from states above approximately 100 kbars have an entirely different character from low pressure curves due to the vaporization and subsequent expansion of the water in the tuff. For the 4 meter cavity calculation, the tuff was shocked to approximately 160 kbars, for the 8 meter cavity to only approximately 10 kbars, while for the tamped calculation, the tuff outside of the initial cavity was shocked to at least 1 mbar. Therefore, the tamped case left a considerable amount of energy behind the ground shock in vaporized water which could not be used to drive the shock, resulting in a narrower shock pulse, giving a smaller peak stress at large distances from the cavity and RDP than the 4 and 8 meter cases.

Similarly, more energy remained inside the cavity from the tamped calculation than in the 4 meter air cavity case at late times due to the vaporized water from tuff in the tamped explosion cavity. Eventually, for larger air filled cavities, the expected decoupling effect occurs.

Figures 3-7 give the computed residual stress fields (σ_r and σ_θ) for all cases previously discussed. (Note that the small amplitude "shock" waves at late times are shown in the figures. These will soon die out.) Additionally, each figure shows what stress field could be expected if somehow the cavity pressure decayed to zero after final cavity formation. Figure 3 shows the stress fields for the tamped cavity calculation with the energy uniformly deposited in 140 tons of tuff. These stresses are fairly typical for area 12 tunnel tuff calculations.

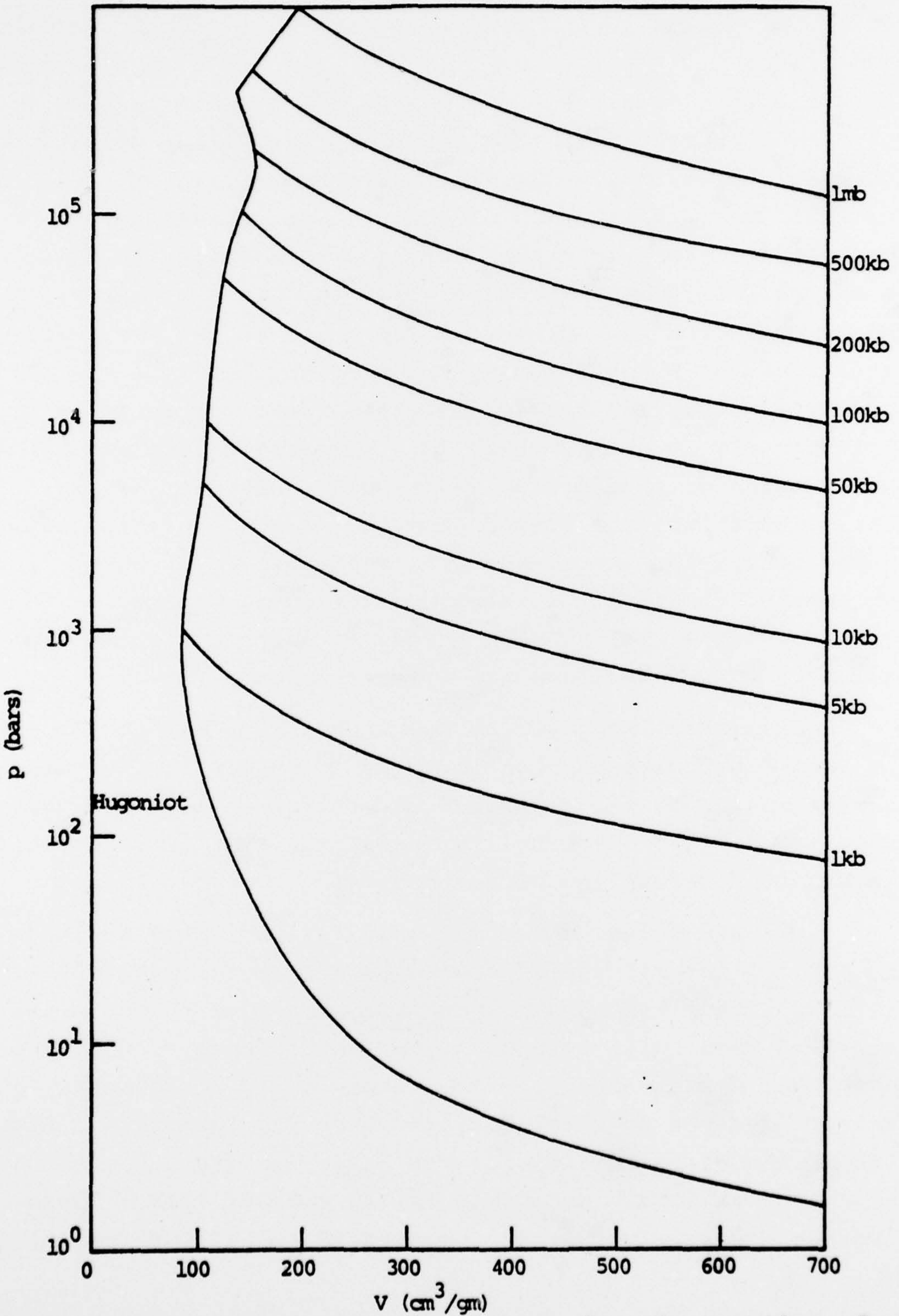

Figure 2. Hugoniot and release adiabats for air equation of state.

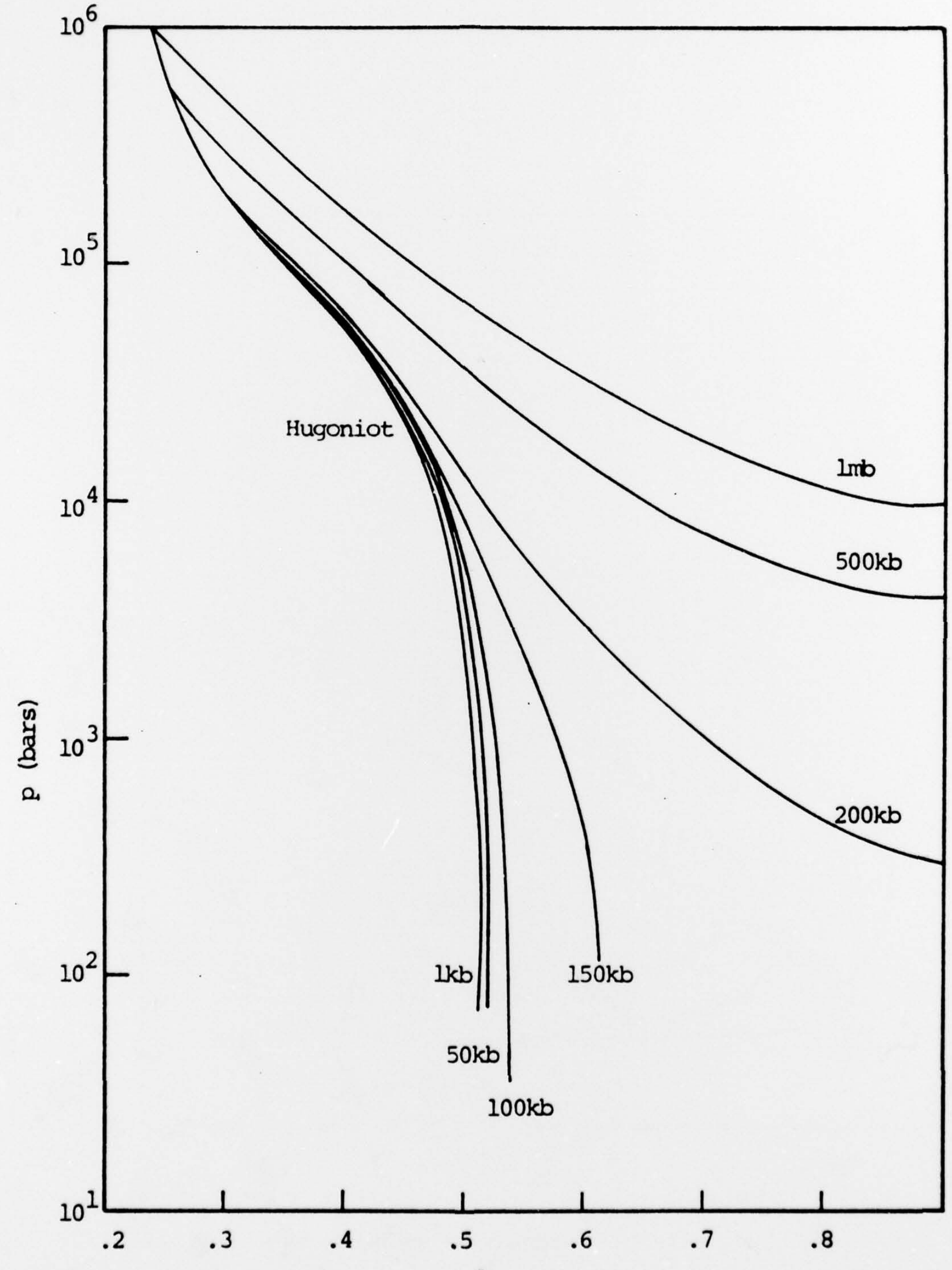

Figure 3. Hugoniot and release adiabats for CHEST 24 equation of state.

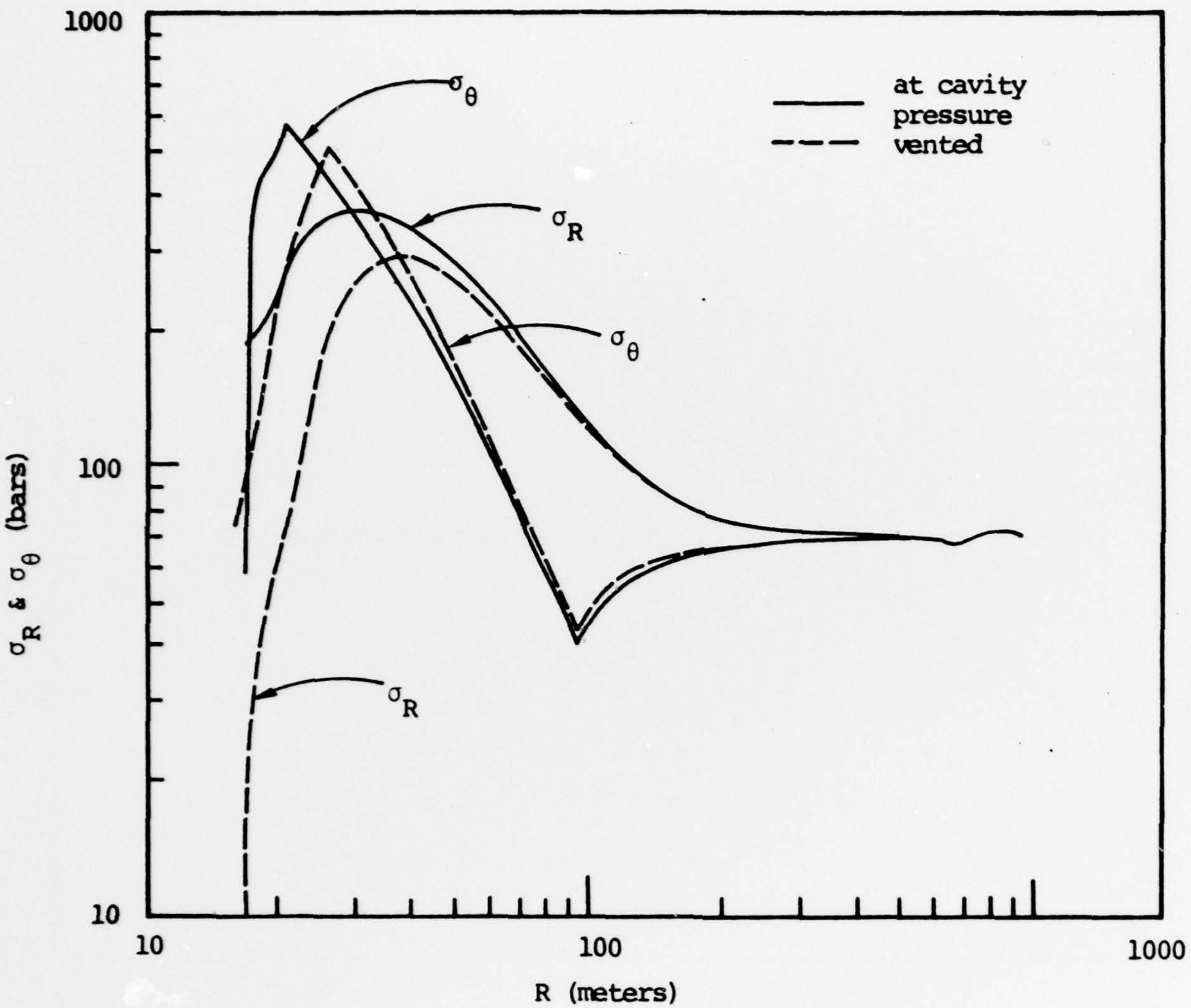

Figure 4. Residual stresses vs. radial distance at full cavity pressure and after cavity pressure has been vented to zero for tamped cavity calculation.

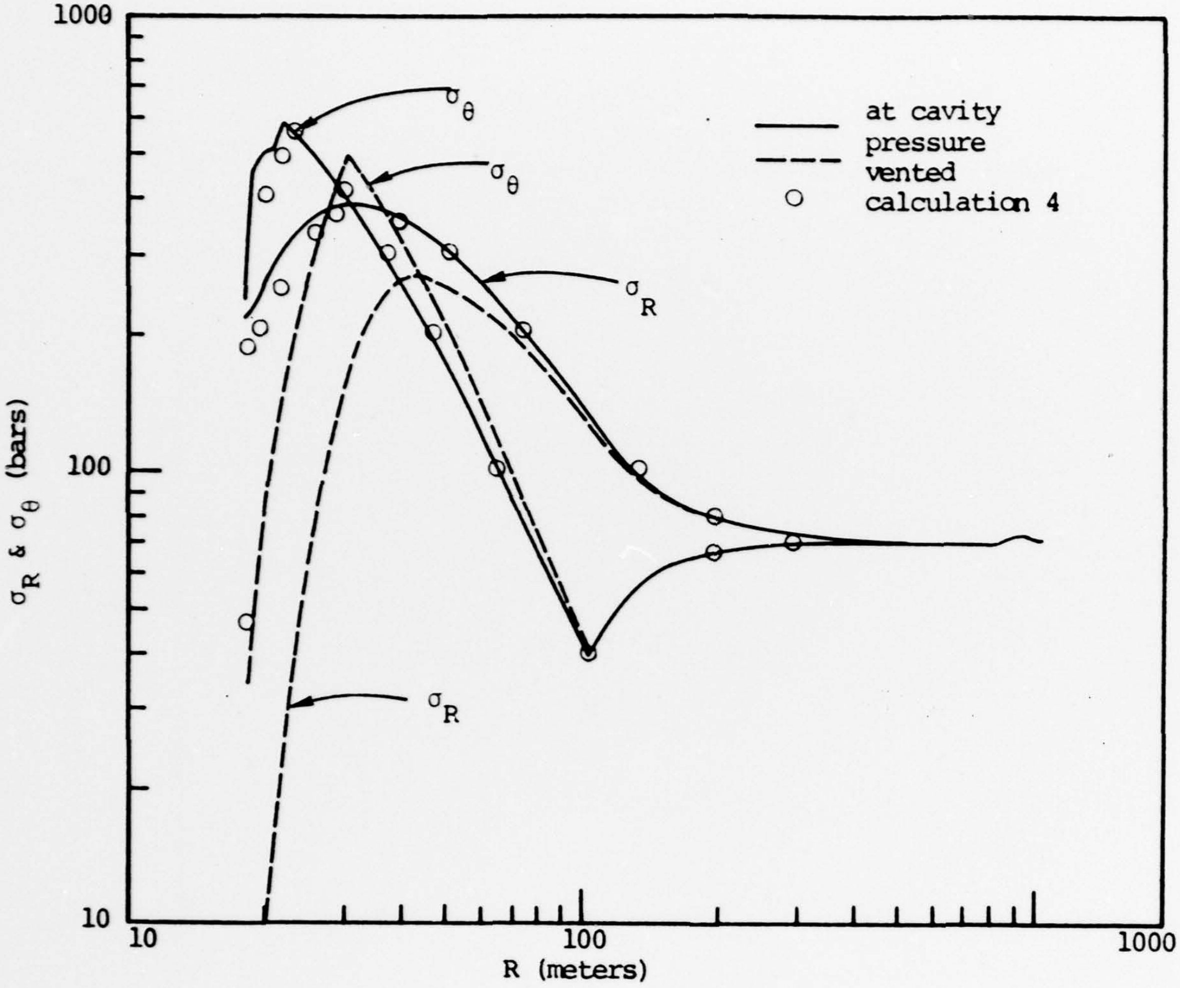

Figure 5. Residual stresses vs. radial distance at full cavity pressure and after cavity pressure has been vented to zero for 4 meter cavity.

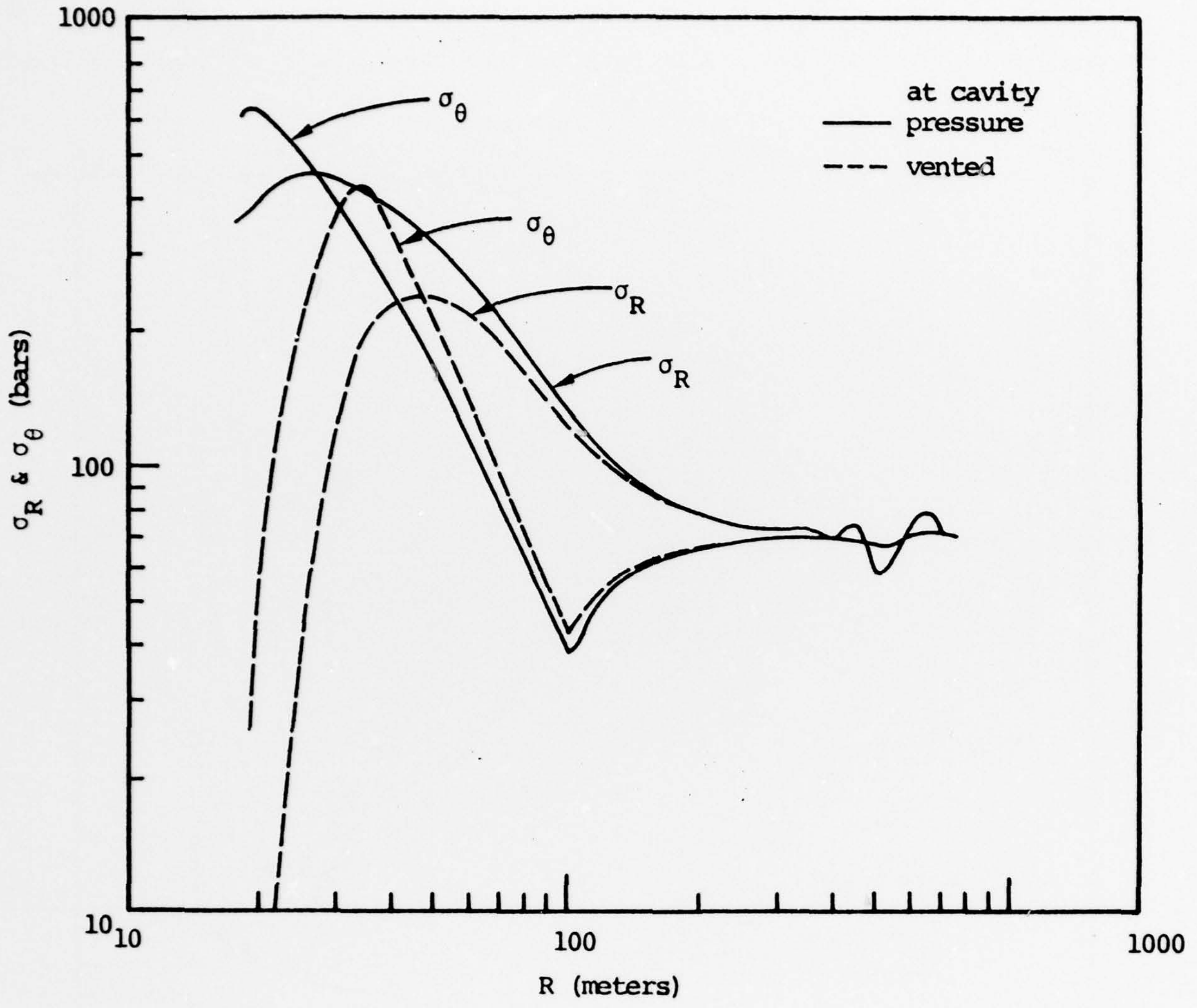

Figure 6. Residual stresses vs. radial distance at full cavity pressure and after cavity pressure has been vented to zero for 8 meter cavity.

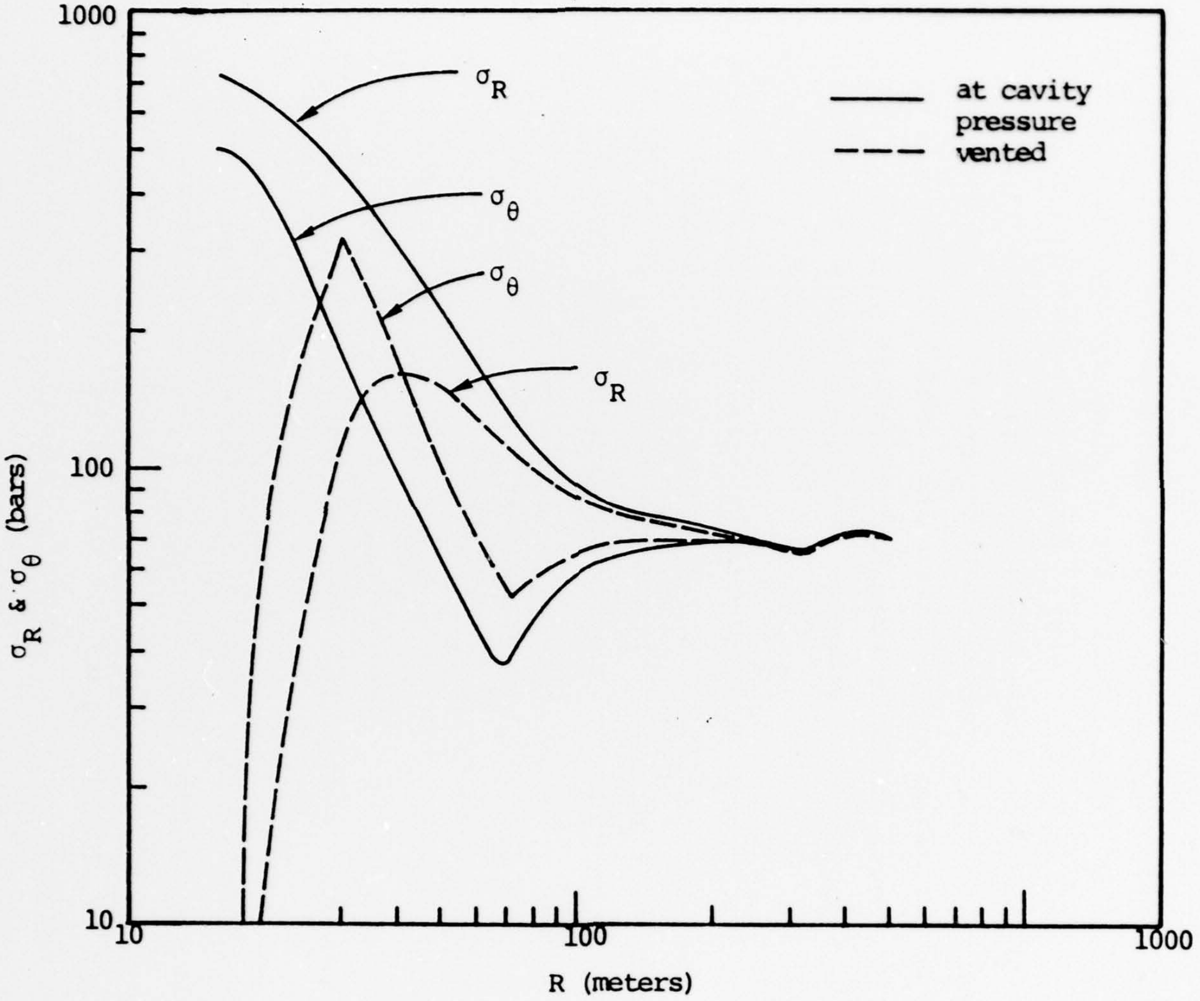

Figure 7. Residual stresses vs. radial distance at full cavity pressure and after cavity pressure has been vented to zero for 16 meter cavity.

Removing the cavity pressure results in an outward and downward shift in the residual stress peaks.

Figure 5 shows the residual stress fields for the 4 meter uniform air filled cavity. These look quite similar to the tamped case. The small circles indicate the results for calculation 4 of Table 1 (when the initial energy was input into 10 percent of the mass of air). These show that the stress field is quite insensitive to the way the calculation is initiated. Figure 6, for the 8 meter cavity, shows a residual stress field similar to the first two cases. However, this stress field must resist a much higher cavity pressure. When this cavity pressure is removed, the stress field is markedly degraded.

Figure 7 shows the calculated "residual" stress fields for the 16 meter cavity. Note that the peak stresses occur immediately at the cavity boundary and that the radial stress is equal to the cavity pressure and greater than the hoop stress. These stresses indicate little or no cavity rebound and do not constitute a residual stress membrane (very little plastic loading has occurred). Approximately 92 percent of the device energy still remains in the cavity threatening to hydrofracture the rock walls. This would seem to be a severe containment risk. When the cavity pressure is removed, some stress field remains.

The results show that placing the device in an air-filled cavity is possible without destroying the residual stress membrane that protects against hydrofracture. However, when the cavity is made large enough to decouple the device, the large cavity pressure is a real threat to explosive containment.

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